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(54) Title: RECEIVERS AND METHODS OF RECEIVING CO-CHANNEL SIGNALS BY CHANNEL SEPARATION AND SUCCESSIVE CANCELLATION
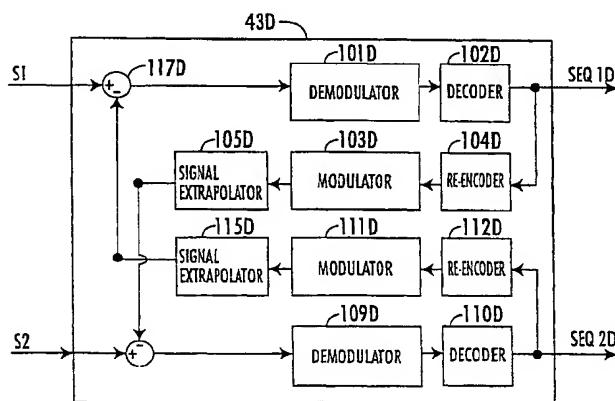
(57) Abstract: A method for receiving a plurality of communications from a respective plurality of transmitters using a common carrier frequency includes receiving a plurality of information signals on a common carrier frequency corresponding to the plurality of communications from the plurality of transmitters, and generating first and second separated signals corresponding to respective first and second ones of the information signals so that the first separated signal includes a primary component corresponding to the first information signal and so that the second separated signal includes a primary component corresponding to the second information signal. The first separated signal is demodulated to provide an estimate of a first information sequence corresponding to the first information signal, and the estimate of the first information sequence is modulated to provide a modulated estimate of the first information sequence. The modulated estimate of the first information sequence is subtracted from the second separated signal to provide and improve second separated signal. The improved second separated signal is demodulated to provide an estimate of a second information sequence corresponding to the second information signal. Related receivers are also discussed.

RECIEVERS AND METHODS OF RECIEVING CO-CHANNEL SIGNALS BY CHANNEL SEPERATION
AND SUCCESSIVE CANCELLATION

FIELD OF THE INVENTION

The present invention relates to the field of communications and more
particularly to communications methods and receivers.

BACKGROUND OF THE INVENTION

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Due to the limited availability of the signal spectrum, cellular
radiotelephone systems have been developed wherein carrier frequencies are
re-used in distant cells to increase spectral efficiency. Because of this
frequency reuse, however, co-channel interference may be present at both

10   mobile terminals and base stations. In response, there have been efforts to
develop signal enhancing receivers to reduce the effects of co-channel
interference. For example, see the reference by Medepalli et al. entitled
"Combined Equalization And CoChannel Interference Cancellation For The
Downlink Using Tentative Decisions" (IEEE 1999) the disclosure of which is

15   hereby incorporated herein in its entirety by reference.

The effects of co-channel interference (CCI) can conventionally be
reduced by providing signal separation in the transmission of different signals.
Cochannel signal separation is conventionally provided in an FDMA system
by providing physical separation between two transmitters using the same

20   carrier frequency and between the respective receiving base stations.
Accordingly, a first signal is received by the first base station at a significantly
higher strength than a second signal, and the second signal is received by the
second base station at a significantly higher strength than the first signal. As
cell sizes are reduced to provide greater capacity, however, the differences in

25   signal strengths may be reduced making it difficult to receive one or both co-
channel signals. Interference from signals transmitted on adjacent carrier
frequencies (adjacent channel interference or ACI) can be accommodated by
filtering the carrier frequency of interest.

In CDMA systems, signal separation is provided during transmission by

30   correlating a first signal with a first spreading code and correlating the second

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signal with a second spreading code. The two signals can then be separated by decorrelating the desired signal with the respective spreading code. In other words, channel separation is provided during transmission through the use of different spreading codes.

5   The reception of co-channel signals without prior signal channel separation during transmission, however, may be difficult. Accordingly, there continues to exist a need for methods and receivers that can receive multiple information signals over a common carrier frequency.

10   SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide improved methods for receiving information signals and related receivers.

It is another object of the present invention to provide methods and receivers that can receive multiple information signals over a common carrier

15   frequency wherein the multiple information signals are transmitted on the common carrier frequency without significant channel separation.

It is still another object of the present invention to provide methods and receivers that can receive multiple information signals over a common carrier frequency wherein the multiple information signals have common signal

20   strengths.

These and other objects can be provided according to the present invention by providing some degree of signal separation at the receiver followed by successive cancellation. The signal separation, for example, can be provided by using spatial and/or temporal processing of co-channel

25   signals, by using cyclostationary properties of the co-channel signals, or by using coding and decoding.

According to a first aspect of the present invention, a plurality of communications are received from a respective plurality of transmitters using a common carrier frequency. In particular, a plurality of information signals

30   are received on a common carrier frequency corresponding to the plurality of communications from the plurality of transmitters. First and second separated baseband signals are generated corresponding to respective first and second ones of the information signals so that the first separated baseband signal includes a primary component corresponding to the first information signal

and so that the second separated baseband signal includes a primary component corresponding to the second information signal. The first separated baseband signal is demodulated to provide an estimate of a first information sequence corresponding to the first information signal. The

5   estimate of the first information sequence is modulated to provide a modulated estimate of the first information sequence, and the modulated estimate of the first information sequence is subtracted from the second separated baseband signal to provide an improved second separated baseband signal. The improved second separated baseband signal is then

10   demodulated to provide an estimate of a second information sequence corresponding to the second information signal.

Moreover, the estimates of the first and second information sequences can be processed to reproduce the first and second communications. By providing the separated baseband signals to have at least some separation,

15   successive cancellation can be used to further improve reception and reproduction of the communications. In addition, the step of modulating the estimate of the first information sequence is preceded by decoding the estimate of the first information sequence to improve the estimate of the first information sequence, and re-encoding the improved estimate of the first

20   information sequence so that the improved and re-encoded estimate of the first information sequence is modulated during the modulating step. The decoding step thus provides a higher degree of signal separation before successive cancellation. The step of subtracting the modulated estimate can also include extrapolating the modulated estimate of the first information

25   sequence to estimate a component of the second separated baseband signal attributable to the first information signal.

More particularly, the step of receiving the plurality of information signals can include receiving first and second co-channel signals from respective first and second antennas. The step of generating the first and

30   second separated baseband signals can thus include combining the first and second co-channel signals according to a first combining branch to generate the first separated baseband signal corresponding to the first information signal, and combining the first and second co-channel signals according to a

second combining branch to generate the second separated baseband signal corresponding to the second information signal.

Alternately, the step of receiving the plurality of information signals can include receiving a co-channel signal. In addition, the step of generating the

5   first and second separated baseband signals can include filtering the co-channel signal using a first filter to generate the first separated baseband signal corresponding to the first information signal, and filtering the co-channel signal using a second filter different from the first filter to generate the second separated baseband signal corresponding to the second information signal.

10   More particularly, the first filter can include a first medium response estimate for the first information signal and the second filter can include a second medium response estimate for the second information signal.

According to yet another alternative, the step of receiving the plurality of information signals can include receiving a co-channel signal. In this

15   alternative, the step of generating the first and second separated baseband signals includes sampling the co-channel signal with a first sampling phase to generate a first sampled co-channel signal, sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate a second sampled co-channel signal, combining the first and second

20   sampled co-channel signals using a first filter combination to provide the first separated baseband signal, and combining the first and second sampled co-channel signals using a second filter combination to provide the second separated baseband signal.

According to still another alternative, the step of receiving the plurality

25   of information signals can include receiving a co-channel signal. Here, the step of generating the first and second separated baseband signals includes sampling the co-channel signal with a first sampling phase to generate the first separated baseband signal, and sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate the

30   second separated baseband signal. The method can also include modulating the estimate of the second information sequence to provide a modulated estimate of the second information sequence, subtracting the modulated estimate of the second communication from the first separated baseband signal to provide an improved first separated baseband signal, and

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demodulating the improved first separated baseband signal to provide an improved estimate of the first information sequence. Additional levels of successive cancellation can thus be provided.

5 According to another aspect of the present invention, a plurality of communications can be received from a respective plurality of transmitters using a common carrier frequency by receiving a plurality of information signals on a common carrier frequency corresponding to the plurality of communications from the plurality of transmitters, and generating a co-channel baseband signal responsive to the plurality of information signals.

10 The co-channel baseband signal is demodulated to provide an estimate of a first information sequence corresponding to a first one of the communications, the estimate of the first information sequence is decoded to improve the estimate of the first information sequence, and the improved estimate of the first information sequence is re-encoded. The improved and re-encoded

15 estimate of the first information sequence is modulated and subtracted from the co-channel baseband signal to provide a second baseband signal, and the second baseband signal is demodulated to provide an estimate of a second information sequence corresponding to a second one of the communications. Decoding and re-encoding can thus provide signal separation for two

20 information signals transmitted on a common carrier frequency.

Methods and receivers according to the present invention thus allow improved reception of multiple information signals transmitted without channel separation over a common carrier frequency.

25   BRIEF DESCRIPTION OF THE DRAWINGS
Figure 1 is a block diagram of a first receiver providing signal separation and successive cancellation according to the present invention.
Figure 2 is a block diagram of a second receiver providing signal separation and successive cancellation according to the present invention.

30 Figures 3A-3D are block diagrams illustrating respective signal reception and separation blocks according to the receiver of Figure 2.
Figures 4A-4D are block diagrams illustrating respective successive cancellation blocks according to the receiver of Figure 2.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many

5   different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Improved reception of a plurality of communications transmitted by a

10   respective plurality of transmitters as information signals over a common carrier frequency can be provided according to the present invention by separating signals to provide a plurality of baseband signals corresponding to the plurality of information signals being received. In particular, a separated baseband signal can be provided for each information signal being received,

15   and successive cancellation can be used to improve the reception of the information signal over the common carrier frequency using the separated baseband signals.

Figure 1 is a block diagram of a receiver providing signal separation and successive cancellation according to a first aspect of the present

20   invention. As shown, the receiver includes a radio processor **19**, a subtractor **21**, a demodulator **23**, a decoder **25**, a re-encoder **27**, a modulator **29**, and a processor **31**. In the receiver of Figure 1, a first information signal is received over a common carrier frequency by demodulating a common co-channel baseband signal from the radio processor **19** and decoding the result to

25   generate an estimate of a first information sequence corresponding to the first stronger information signal. The estimate of the first information sequence is then re-encoded, modulated, and subtracted from the common co-channel baseband signal to provide a second baseband signal. This second baseband signal is then demodulated and decoded to provide an estimate of

30   a second information sequence corresponding to a second information signal received over the common carrier frequency. While performance can be improved when the first information signal is stronger than the second information signal, receivers and methods according to the diagram of Figure

1 can be used to receive first and second information signals having relatively equal strengths.

In other words, the channel coding/decoding power used in wireless mobile radio systems can be used to obtain signal separation for multiple

5   information signals transmitted without channel separation over a common carrier frequency. After generating an estimate a first information sequence corresponding to a first information signal, the re-encoded and modulated first information sequence is subtracted from the common baseband signal to allow an estimation of a second information sequence corresponding to a

10   second information signal. In particular, by decoding the estimate of the first information sequence, the estimate of the first information sequence is improved so that after re-encoding and modulating, the improved estimate of the first information sequence can be subtracted from the common baseband signal to effectively provide a second separated baseband signal used to

15   obtain the second information sequence. The successive cancellation is thus employed after decoding.

In greater detail, a plurality of information signals **IS1** and **IS2** from a corresponding plurality of remote transmitters **T1** and **T2** can be received on a common carrier frequency at the antenna **17** wherein each information signal

20   represents a respective communication transmitted by a respective transmitter. The radio processor **19** provides a common co-channel baseband signal including components corresponding to each of the plurality of information signals. While any number of information signals representing respective communications can be transmitted on the common carrier

25   frequency, two information signals will be discussed with respect to the receiver of Figure 1.

The strongest of the information signals **IS1** (if the signal strengths are different) received on the common carrier frequency can be determined based on the signal strength which can be obtained from the channel estimates, and

30   this strongest information signal can be demodulated using the demodulator **23** and decoded using the decoder **25** to provide an estimate of a corresponding first information sequence transmitted from the remote transmitter **T1**. This combination of demodulation and decoding thus provides a separation of the first information sequence corresponding to the first

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information signal **IS1** with respect to the plurality of information sequences and corresponding communications.

The estimate of the first information sequence is then re-encoded using re-encoder **27** and modulated using modulator **29** to reconstruct a relatively

5   clean version of the portion of the common co-channel baseband signal corresponding to the strongest information signal **IS1**. The portion of the common co-channel baseband signal corresponding to the strongest information signal **IS1** is then subtracted from the total common co-channel baseband signal using the subtractor **21** so that the remaining portion of the

10   baseband signal corresponds to a second weaker information signal **IS2**. The remaining portion of the baseband signal is then demodulated using the demodulator **23** and decoded using the decoder **25** to provide an estimate of a second information sequence corresponding to the second weaker information signal **IS2** from the second remote transmitter **T2**.

15   The estimate of the first and second information sequences can then be processed using processor **31** to reproduce the corresponding first and second communications. In a radiotelephone base station, for example, first and second communications can be reproduced to provide voice communications. Alternately, the first and second communications can be

20   reproduced to provide data communications. In addition, the process can be repeated in additional stages for further improvements of the reproduced communications. The estimate of the second information sequence, for example, can be re-encoded, modulated, and subtracted from the common co-channel baseband signal to further improve the estimate of the first

25   information sequence. This improved estimation of the first information sequence can then be used to further improve the estimate of the second information sequence, with any number of subsequent stages of successive cancellation being used. In addition, the estimates of the first and second information sequences can both be re-encoded, modulated, and subtracted

30   from the common co-channel baseband signal to obtain a third information sequence corresponding to a third information signal transmitted over the common carrier frequency from a third transmitter.

Furthermore, the decoder **25** can perform a cyclical redundancy check (CRC) on the estimate of the first information sequence. If the estimate of

the first information sequence passes the cyclical redundancy check, the estimate of the first information sequence can be re-encoded, modulated and subtracted from the common co-channel baseband signal to obtain an estimate of the second information sequence. If the cyclical redundancy

5   check fails, the estimate of the first information sequence may not be sufficiently accurate to reliably obtain an estimate of the second information sequence so that successive cancellation is not performed when the cyclical redundancy check fails. Similarly, a bit error rate (BER) may be determined for the first information sequence so that successive cancellation is not

10   performed if the bit error rate is greater than a predetermined value.

In summary, multiple information signals **IS1** and **IS2** can be received at the antenna **17** over a common carrier frequency wherein the information signals are transmitted without channel separation. It will be understood that multiple antennas can also be used. Responsive to the multiple information

15   signals, the radio processor **19** generates the common co-channel baseband signal including portions thereof corresponding to both the multiple information signals received at the antenna. In greater detail, the radio processor **19** can amplify, mix, filter, sample, and quantize all signals received on the common carrier frequency to extract the common co-channel

20   baseband signal including portions corresponding to both information signals **IS1** and **IS2**. The common co-channel baseband signal can be used to estimate channel parameters from both information signals **IS1** and **IS2** using a channel estimation algorithm such as joint channel estimation or other conventional channel estimation algorithms. The channel estimates can then

25   be used to determine the strongest information signal received at the antenna **17**.

The common co-channel baseband signal is then demodulated using demodulator **23** and decoded using decoder **25** to provide an estimate of a first information sequence corresponding to the strongest information signal.

30   The estimate of the first information sequence can then be processed using the processor **31** to reproduce the communication from the first transmitter **T1** transmitted as the first information signal **IS1**. Alternately, the estimate of the first information sequence can be further improved using successive cancellation before reproducing the corresponding communication.

The estimate of the first information sequence is then re-encoded using re-encoder **27**, modulated using modulator **29**, and subtracted from the common co-channel baseband signal using subtractor **21**. In other words, baseband samples corresponding to the strongest information signal **IS1** are

5   subtracted from the common co-channel baseband signal to provide a second baseband signal with a primary component corresponding to the second weaker information signal **IS2**. This second baseband signal is then demodulated using the demodulator **23** and decoded using the decoder **25** to provide an estimate of a second information sequence corresponding to the

10   second information signal **IS2**. The estimate of the second information sequence can then be processed using processor **31** to reproduce the communication from the second transmitter **T2** transmitted as the second information signal **IS2**.

In addition, the estimate of the second information sequence can be re-

15   encoded using re-encoder **27**, modulated using modulator **29**, and subtracted from the common co-channel baseband signal using subtractor **21**. Baseband samples corresponding to the weaker information signal **IS2** are thus subtracted from the common co-channel baseband signal to provide a third baseband signal more closely matching the first information signal. This

20   third baseband signal can then be demodulated and decoded to provide an improved estimate of the first information sequence corresponding to the first information signal **IS1**. This improved estimate of the first information sequence can then be processed to reproduce the communication from the first transmitter. This improved estimate of the first information sequence can

25   also be used in a subsequent phase of successive cancellation to further improve the estimate of the second information sequence.

Figure 2 illustrates a block diagram of a second receiver according to the present invention using spatial and/or temporal processing of co-channel signals to provide separated baseband signals for different information signals

30   received over a common carrier frequency wherein the information signals are transmitted without channel separation. In particular, the signal reception and separation block **41** can be used to receive a plurality of information signals over a common carrier frequency and to provide separated baseband signals **S1** and **S2** corresponding to respective information signals received from

remote transmitters. In particular, the first separated baseband signal can include a primary component corresponding to a first information signal and the second separated baseband signal can include a primary component corresponding to a second information signal. The successive cancellation

5   block **43** is then used to further improve the signal separation thus providing information sequences **Seq1** and **Seq2**. The information sequences **Seq1** and **Seq2** can then be processed using processor **45** to reproduce communications from respective transmitters.

Various structures for providing signal reception and separation for the

10   receiver of Figure 2 are illustrated in Figure 3A-3D. In particular, Figure 3A illustrates signal reception and separation using antenna combining. As shown, multiple antennas **A1** and **A2** each receive the information signals **IS1** and **IS2** from respective transmitters **T1** and **T2** over a common carrier frequency. The radio processor **51** amplifies, mixes, filters, samples, and

15   quantizes the signals from the antennas to provide common co-channel baseband signals **BS1** and **BS2** corresponding to the respective antennas **A1** and **A2**. Two antenna combining branches **53** and **55** respectively corresponding to the information signals **IS1** and **IS2** combine the common co-channel baseband signals **BS1** and **BS2** from the different antennas to

20   respectively increase the effect of one information signal and decrease the effect of the other information signal using spatial processing techniques.

In particular, the antenna combining branch **53** combines the common co-channel baseband signals **BS1** and **BS2** so as to increase the effect of information signal **IS1** and decrease the effect of the effect of information

25   signal **IS2** in the resulting baseband signal **S1A**. Similarly, the antenna combining branch **55** combines the common co-channel baseband signals **BS1** and **BS2** so as to increase the effect of information signal **IS2** and decrease the effect of the effect of information signal **IS1** in the resulting baseband signal **S2A**. Accordingly, even if the strengths of the information

30   signals **IS1** and **IS2** are on the same order, antenna combining can be used to provide some separation of the different information signals in the baseband signals **S1A** and **S2A** when the information signals are transmitted without channel separation. In other words, the separated baseband signal **S1A** includes a primary component corresponding to the information signal **IS1**,

and the separated baseband signal **S2A** includes a primary component corresponding to the information signal **IS2**.

In particular, antenna combining techniques such as maximal ratio combining (MRC) or interference cancellation combining can be used in the
5   antenna combining branches **53** and **55**. Various combining techniques are also discussed in the reference by Jack H. Winters entitled "Optimum Combining for Indoor Radio Systems with Multiple Users" (*IEEE Trans. Commun.*, pp. 1222-1230, Nov. 1987) and the reference by H. Yoshino et al. entitled "Interference Cancelling Characteristics of DFE Transversal-
10 Combining Diversity in Mobile Radio Environment - Comparison with Metric-Combining Schemes" (*Electronics and Commun. in Japan*, pp. 85-98, Part 1, vol. 77, No. 9, 1994). The disclosures of both of these references are hereby incorporated herein in their entirety by reference.

The separated baseband signals **S1A** and **S2A** are then subjected to
15 successive cancellation as discussed above with regard to the successive cancellation block **43**. In general, the separated baseband signal corresponding to the strongest information signal is demodulated, remodulated, and then extrapolated before being subtracted from the separated baseband signal corresponding to the weaker information signal.
20 Successive cancellation will be discussed in greater detail below with regard to Figures 4A to 4D.

The separated baseband signals **S1A** and **S2A** can thus be provided so that information signal **IS1** is emphasized in separated baseband signal **S1A** and so that the information signal **IS2** is emphasized in the separated
25 baseband signal **S2A**. Successive cancellation can then be employed using the separated baseband signals. While only two antennas and two information signals are illustrated in Figure 3A, it will be understood that any number of antenna signals and any number of antenna combining branches can be provided according to the present invention. Moreover, the separation
30 techniques discussed above with regard to Figure 3A can be used with more than two co-channel information signals.

Figure 3B illustrates signal reception and separation using using the frequency selectiveness of a fading channel which could be particularly useful in systems with severely frequency selective channels such as GSM. In other

words, temporal processing is used to provide signal separation. As shown, intentional or non-intentional frequency selectivity allows separation of co-channel signals after implementing receive filtering in the radio processor **61** using second stage medium filters **63** and **65** which can be matched filters.

5   Alternately, the filters **63** and **65** can be designed so that interference on each branch is reduced. In other words, the filters **63** and **65** do not have to be matched, but could instead be interference rejection filters based on the channel tap estimates of the desired and co-channel medium responses. Conventional time and space filtering is discussed, for example, in the

10   reference by William A. Gardner entitled "Cyclic Wiener Filtering: Theory and Method." (IEEE Transactions on Communications, Vol. 41, No. 1, January 1993.)

As shown in Figure 3B, the information signals **IS1** and **IS2** are transmitted by the remote transmitters **T1** and **T2** over a common carrier

15   frequency at the antenna. The co-channel signals are processed by the radio processor **61** which amplifies, mixes, filters, samples, and quantizes the signal to extract a common co-channel baseband signal including components of both information signals **IS1** and **IS2**. The common co-channel baseband signal is filtered using the filter **63** based on a medium response estimate of

20   the first information signal and using the filter **65** based on a medium response estimate of the second information signal. In other words, signal separation is dependent on time alignment of each information signal. Accordingly, the medium responses and the time alignments of each signal are estimated.

25   For example, the medium response estimates for the first information signal **IS1** can be used for the first filter **63**, and the medium response estimate for the second information signal **IS2** can be used for the second filter **65**. The medium responses corresponding to different signals can be estimated using joint channel estimation before these filters. The separated

30   baseband signals **S1B** and **S2B** are thus provided, and successive cancellation can be used as discussed in greater detail below.

Figure 3C illustrates signal reception and separation using spectral redundancy to provide signal separation. In particular, signals from different fractional samples (with filters to reduce the sum of filtered error signals) can

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be used to suppress interference and to provide signal separation. In general, signal separation prior to successive cancellation is not expected to eliminate interference components of the separated baseband signals **S1C** and **S2C**, and spectral redundancy can be used to provide a degree of signal separation

5   when the strengths of the received information signals are on the same order. Successive cancellation can then be applied to the separated baseband signals to further reduce interference components of the two branches. Filtering is discussed in the Gardner reference (cited above), the disclosure of which is hereby incorporated herein in its entirety by reference.

10   As shown in Figure 3C, co-channel signals including information signals **IS1** and **IS2** are received at the antenna and processed in the radio processor **71** which amplifies, mixes, filters, samples, and quantizes the co-channel signals to provide a common co-channel baseband signal. The common co-channel baseband signal is sampled using different sampling

15   phases (**kT** and **kT+T/2**); filtered using filters **73, 75, 77,** and **79**; and combined using combiners **81** and **83** to provide the separated baseband signals **S1C** and **S2C** corresponding to the information signals **IS1** and **IS2**. Successive cancellation can then be used as discussed in greater detail below. Although only two sampling phases are discussed here, receivers and

20   methods according to Figure 3C can be provided according to the present invention with more than two sampling phases.

The signal reception and separation approaches discussed above with regard to Figures 3A-3C assume that the information signals **IS1** and **IS2** are both symbol and slot synchronized. If the co-channel signals, however, are

25   not slot and symbol synchronized, signal separation can be obtained using multiple sampling phases which are preferential for each of the co-channel signals. Using knowledge of pulse shapes and medium taps, the first information signal can be re-constructed at the sampling phase of the second information signal and subtracted from the second information signal. The

30   timing difference can thus be exploited for the separation of co-channel signals. This approach can be extended to dispersive cases which require the timing of the different taps for both co-channel signals.

As shown in Figure 3D, two different radio processors **91** and **93** are used to process the co-channel information signals **IS1** and **IS2**. The first

radio processor **91** amplifies, mixes, filters, samples, and quantizes the co-channel signal with a sampling phase that is preferential with respect to the first co-channel signal. Similarly, the second radio processor **93** amplifies, mixes, filters, samples, and quantizes the co-channel signal with a sampling

5   phase that is preferential with respect to the second co-channel signal. The separated baseband signals **S1D** and **S2D** are further processed using the successive cancellation techniques discussed below. Methods for reducing co-channel interference are discussed, for example, in U.S. Patent Application Serial No. 09/143,821 entitled "Methods and Systems for Reducing Co-

10 Channel Interference Using Multiple Timings for Received Signal" filed August 31, 1998. The disclosure of this application is hereby incorporated herein in its entirety by reference. It is further noted that Application Serial No. 09/143,821 is assigned to the assignee of the present invention, and that Application Serial No. 09/143,821 and the present invention share a common

15 inventor.

Various successive cancellation blocks according to Figure 2 are illustrated in Figures 4A to 4D. In particular, Figure 4A illustrates a successive cancellation block including a first demodulator **101A**, a modulator **103A**, a signal extrapolator **105A**, subtractor **107A**, and a second demodulator **109A**.

20 Two separated baseband signals **S1** and **S2** are provided from the signal reception and separation block **41**, as shown in Figure 2. The separated baseband signals can be provided according to any of the reception and separation techniques discussed above with regard to Figures 3A-3D or other reception and separation techniques.

25 The separated baseband signal **S1** corresponding to the stronger information signal **IS1** received over the common carrier frequency can be demodulated using demodulator **101A** to provide an estimate of the information sequence **Seq1A** corresponding to the information sequence **IS1**. As discussed above, the strongest information signal can be determined using

30 channel estimates. The channel estimates can be recalculated in each branch or extracted using information from prior blocks if the channel estimates have been previously estimated. Alternately, the information signals can have approximately equal strengths or the separated baseband signal corresponding to the weaker information signal can be processed first.

The estimate of the information sequence **Seq1A** is then modulated using modulator **103A** to reconstruct the separated baseband signal **S1**, and the reconstructed baseband signal is extrapolated using signal extrapolator **105A** to estimate the effect of the first information signal on the second

5   separated baseband signal **S2**. The extrapolated signal is then subtracted from the second separated baseband signal **S2** to provide more accurate demodulation of the second information signal thus providing a more accurate estimate of the second information sequence **Seq2B**. The two information sequences **Seq1A** and **Seq1B** can then be processed using processor **45** to

10   reproduce communications corresponding to information signals **IS1** and **IS2** corresponding to transmitters **T1** and **T2**. The processor **45**, for example, can decode each of the information sequences to further improve the estimates thereof.

Figure 4B illustrates a successive cancellation block including a first

15   demodulator **101B**, a modulator **103B**, a signal extrapolator **105B**, subtractor **107B**, and a second demodulator **109B**. In addition, the successive cancellation block of Figure 4B includes first and second decoders **102b** and **110B** and encoder **104B**. The successive cancellation block of Figure 4B is similar to that of Figure 4A with the exception that the estimate of the first

20   information sequence is decoded using decoder **102B** and re-encoded using re-encoder **104B** before modulating and extrapolating the estimate of the first information sequence using modulator **103B** and signal extrapolator **105B**. The estimate of the first information sequence can thus be improved after demodulation and before subtraction to provide a more accurate baseband

25   signal representation of the second information signal. The decoder **110B** provides that both estimates of the information sequences are decoded before the processor **45**. Accordingly, the processor does not need to perform decoding functions.

Figures 4C and 4D illustrate successive cancellation blocks

30   respectively corresponding to the blocks of Figures 4A and 4B. The successive cancellation block of Figure 4C, for example, includes a first demodulator **101C**, a modulator **103C**, a signal extrapolator **105C**, subtractor **107C**, and a second demodulator **109C** that operate as discussed above with regard to Figure 4A to subtract a modulated and extrapolated estimate of the

first information sequence **Seq1C** from the second separated baseband signal **S2** before modulating the second separated baseband signal. In addition, the estimate of the second information sequence **Seq2C** is then modulated using modulator **111C**, extrapolated using signal extrapolator **115C**, and subtracted

5   from the first separated baseband signal **S1** so that the estimate of the information sequence **Seq1C** can be further improved. By subtracting the modulated and extrapolated estimate of the second information sequence from the first separated baseband signal **S1**, the effects of the second information signal can be reduced in the determination of a second and

10   improved estimate of the first information sequence **Seq1D**. Additional stages of successive cancellation can be provided, for example, by modulating, extrapolating, and subtracting the second estimate of the first information sequence from the second separated baseband signal to provide a second and improved estimate of the second information sequence. Any number of

15   improved estimates of the first and second information sequences can thus be provided by providing additional stages of successive cancellation.

The successive cancellation block of Figure 4D is similar to that of Figure 4C with the addition of decoders **102D** and **110D** and re-encoders **104D** and **112D**. As discussed above with regard to Figure 4B, the decoders

20   and re-encoders further improve the estimates of the information sequences before subtraction from separated baseband signals. In other words, the use of the decoders in the successive cancellation loop can provide a higher degree of signal separation and can thus allow the generation of more accurate estimates of the information sequences.

25   As discussed above with regard to Figure 1, any stage of successive cancellation can be proceeded by determining a level of accuracy of the estimate of the information sequence. For example, a cyclical redundancy check (CRC) can be performed or a bit error rate (BER) can be determined for the estimate of the information sequence. If the estimate of the information

30   sequence has a desired level of accuracy (i.e., the cyclical redundancy check passes, or a desired bit error rate is achieved), the successive cancellation may proceed. If the estimate of the information sequence does not have the desired level of accuracy, the estimate of the information sequence may not be sufficiently reliable to justify successive cancellation. Accordingly, a

subsequent stage of successive cancellation may not be performed. In Figures 4A and 4C, for example, the accuracy of each information sequence can be determined at a respective demodulator. In Figures 4B and 4D, for example, the accuracy of each information sequence can be determined at a

5   respective demodulator and/or decoder.

Although the signals are demodulated and subtracted successively in the embodiments discussed above, signal separation according to the present invention can also be applied to parallel cancellation of co-channel signals, where the signals are demodulated, decoded, re-encoded, remodulated and

10   subtracted from each other in parallel (at the same time).

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the

15   following claims. While various signal separation and successive cancellation techniques have been discussed above, those having skill in the art will understand that the present invention can be implemented with other signal separation and/or successive cancellation techniques.

THAT WHICH IS CLAIMED IS:

1.   A method for receiving a plurality of communications from a
respective plurality of transmitters using a common carrier frequency, the
method comprising the steps of:
        receiving a plurality of information signals on a common carrier
5   frequency corresponding to the plurality of communications from the plurality
of transmitters;
        generating first and second separated signals corresponding to
respective first and second ones of the information signals so that the first
separated signal includes a primary component corresponding to the first
10   information signal and so that the second separated baseband signal includes
a primary component corresponding to the second information signal;
        demodulating the first separated signal to provide an estimate of a first
information sequence corresponding to the first information signal;
        modulating the estimate of the first information sequence to provide a
15   modulated estimate of the first information sequence;
        subtracting the modulated estimate of the first information sequence
from the second separated signal to provide an improved second separated
baseband signal; and
        demodulating the improved second separated signal to provide an
20   estimate of a second information sequence corresponding to the second
information signal.

2.   A method according to Claim 1 further comprising the step of:
        processing the estimates of the first and second information sequences
to reproduce the first and second communications.

3.   A method according to Claim 1 wherein the step of modulating
the estimate of the first information sequence is preceded by the steps of:
        decoding the estimate of the first information sequence to improve the
estimate of the first information sequence; and

5   after the step of decoding, re-encoding the improved estimate of the

first information sequence so that the improved and re-encoded estimate of

the first information sequence is modulated during the modulating step.

4.   A method according to Claim 1 wherein the step of subtracting

the modulated estimate comprises extrapolating the modulated estimate of

the first information sequence to estimate a component of the second

separated signal attributable to the first information signal.

5.   A method according to Claim 1:

wherein the step of receiving the plurality of information signals

comprises receiving first and second co-channel signals from respective first

and second antennas; and

5   wherein the step of generating the first and second separated signals

comprises the steps of,

combining the first and second co-channel signals according to

a first combining branch to generate the first separated signal

corresponding to the first information signal, and

10   combining the first and second co-channel signals according to

a second combining branch to generate the second separated signal

corresponding to the second information signal.

6.   A method according to Claim 1:

wherein the step of receiving the plurality of information signals

comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5   comprises the steps of,

filtering the co-channel signal using a first filter to generate the

first separated signal corresponding to the first information signal, and

filtering the co-channel signal using a second filter different from

the first filter to generate the second separated signal corresponding to

10   the second information signal.

7.　　A method according to Claim 6 wherein the first filter comprises a first medium response estimate including time estimation for the first information signal and the second filter comprises a second medium response estimate including timing estimation for the second information signal.

8.　　A method according to Claim 1:

wherein the step of receiving the plurality of information signals comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5　　comprises the steps of,

sampling the co-channel signal at a first sampling phase to generate a first sampled co-channel signal,

sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate a second sampled

10　　co-channel signal,

combining the first and second sampled co-channel signals using a first filter combination to provide the first separated signal, and

combining the first and second sampled co-channel signals using a second filter combination to provide the second separated

15　　signal.

9.　　A method according to Claim 1:

wherein the step of receiving the plurality of information signals comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5　　comprises the steps of,

sampling the co-channel signal with a first sampling phase to generate the first separated signal, and

sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate the second

10　　separated signal.

10.   A method according to Claim 1 further comprising the steps of:

modulating the estimate of the second information sequence to provide a modulated estimate of the second information sequence;

subtracting the modulated estimate of the second communication from
5   the first separated signal to provide an improved first separated signal; and

demodulating the improved first separated signal to provide an improved estimate of the first information sequence.

11.   A method according to claim 1 wherein the first and second separate signals comprise first and second separated baseband signals.

12.   A method according to Claim 1 wherein modulating the estimate of the first information sequence is preceded by:

checking the first information sequence for a predetermined level of accuracy wherein the modulated estimate of the first information sequence is
5   not subtracted if the first information sequence does not meet the predetermined level of accuracy.

13.   A method for receiving a plurality of communications from a respective plurality of transmitters using a common carrier frequency, the method comprising the steps of:

receiving a plurality of information signals on a common carrier
5   frequency corresponding to the plurality of communications from the plurality of transmitters;

generating a co-channel signal responsive to the plurality of information signals;

demodulating the co-channel signal to provide an estimate of a first
10   information sequence corresponding to a first one of the communications;

decoding the estimate of the first information sequence to improve the estimate of the first information sequence;

re-encoding the improved estimate of the first information sequence;

modulating the improved and re-encoded estimate of the first
15   information sequence;

22

subtracting the modulated estimate of the first information sequence from the co-channel signal to provide a second signal; and

demodulating the second signal to provide an estimate of a second information sequence corresponding to a second one of the communications.

14.   A method according to Claim 13 further comprising the step of:

processing the estimates of the first and second information sequences to reproduce the first and second communications.

15.   A method according to Claim 13 further comprising the step of:

decoding the estimate of the second information sequence to improve the estimate of the second information sequence.

16.   A method according to Claim 15 further comprising the steps of:

re-encoding the improved estimate of the second information sequence;

modulating the improved and re-encoded estimate of the second
5   information sequence;

subtracting the modulated estimate of the second information sequence from the co-channel baseband signal to provide a third baseband signal; and

demodulating the third baseband signal to provide a second estimate
10   of the first communication.

17.   A method according to Claim 14 further comprising the step of:

decoding the second estimate of the first information sequence.

18.   A method according to Claim 13 wherein the co-channel signal comprises a co-channel baseband signal and wherein the second channel comprises a second baseband signal.

19.   A method according to Claim 13 wherein modulating the improved and re-encoded estimate of the first information sequence is preceded by:

checking the improved estimate of the first information sequence for a

5   predetermined level of accuracy wherein the modulated estimate of the first

information sequence is not subtracted from the co-channel signal if the first

information sequences does not meet the predetermined level of accuracy.

20.   A method for receiving a plurality of communications from a

respective plurality of transmitters using a common carrier frequency, the

method comprising the steps of:

receiving a plurality of information signals on the common carrier

5   frequency corresponding to the plurality of communications from the plurality

of transmitters;

generating a first signal responsive to the plurality of information

signals;

generating an estimate of a first information sequence corresponding to

10   a first one of the communications responsive to the first signal;

modulating the estimate of the first information sequence;

subtracting the modulated estimate of the first information sequence

from a second signal to provide a third signal; and

demodulating the third signal to provide an estimate of a second

15   information sequence corresponding to a second one of the communications.

21.   A method according to Claim 20 further comprising the step of:

processing the estimates of the first and second information sequences

to reproduce the first and second communications.

22.   A method according to Claim 20 wherein the first and second

signals comprise a common signal.

23.   A method according to Claim 20 wherein the first signal includes

a primary component corresponding the first information sequence, and

wherein the second signal includes a primary component corresponding to the

second information sequence.

24.   A method according to Claim 16 wherein the first, second, and third signals comprise first, second, and third baseband signals.

25.   A receiver that receives a plurality of communications from a respective plurality of transmitters using a common carrier frequency, the receiver comprising:

        a signal separator that generates first and second separated signals
5   corresponding to respective first and second ones of the information signals so that the first separated signal includes a primary component corresponding to the first information signal and so that the second separated signal includes a primary component corresponding to the second information signal;

        a first demodulator that demodulates the first separated signal to
10   provide an estimate of a first information sequence corresponding to the first information signal;

        a modulator that modulates the estimate of the first information sequence to provide a modulated estimate of the first information sequence;

        a subtractor that subtracts the modulated estimate of the first
15   information sequence from the second separated signal to provide an improved second separated signal; and

        a second demodulator that demodulates the improved second separated signal to provide an estimate of a second information sequence corresponding to the second information signal.

26.   A receiver according to Claim 25 further comprising:

        a processor that processes the estimates of the first and second information sequences to reproduce the first and second communications.

27.   A receiver according to Claim 25 further comprising:

        a decoder that decodes the estimate of the first information sequence to improve the estimate of the first information sequence; and

        a re-encoder that re-encodes the improved estimate of the first
5   information sequence so that the improved and re-encoded estimate of the first information sequence is modulated by the modulator.

28.   A receiver according to Claim 25 further comprising:

a signal extrapolator that extrapolates the modulated estimate of the first information sequence to estimate a component of the second separated signal attributable to the first information signal so that the subtractor

5   subtracts the modulated and extrapolated estimate of the first information sequence.

29.   A receiver according to Claim 25 wherein the first and second co-channel signals are received from respective first and second antennas, and wherein the signal separator combines the first and second co-channel signals according to a first combining branch to generate the first separated

5   signal corresponding to the first information signal, and combines the first and second co-channel signals according to a second combining branch to generate the second separated signal corresponding to the second information signal.

30.   A receiver according to Claim 25 wherein the signal separator filters the co-channel signal using a first filter to generate the first separated signal corresponding to the first information signal, and filters the co-channel signal using a second filter different from the first filter to generate the second

5   separated signal corresponding to the second information signal.

31.   A receiver according to Claim 30 wherein the first filter comprises a first medium response estimate including timing information for the first information signal and the second filter comprises a second medium response estimate including timing information for the second information

5   signal.

32.   A receiver according to Claim 25 wherein the signal separator samples the co-channel signal with a first sampling phase to generate a first sampled co-channel signal, samples the co-channel signal with a second sampling phase different than the first sampling phase to generate a second

5   sampled co-channel signal, combines the first and second sampled co-channel signals using a first filter combination to provide the first separated

signal, and combines the first and second sampled co-channel signals using a second filter combination to provide the second separated signal.

33.   A receiver according to Claim 25 wherein the signal separator samples the co-channel signal with a first sampling phase to generate the first separated signal, and samples the co-channel signal with a second sampling phase different than the first sampling phase to generate the second

5   separated signal.

34.   A receiver according to Claim 25 further comprising:
a second modulator that modulates the estimate of the second information sequence to provide a modulated estimate of the second information sequence; and

5   a second subtractor that subtracts the modulated estimate of the second communication from the first separated signal to provide an improved first separated signal;
wherein the first demodulator demodulates the improved first separated signal to provide an improved estimate of the first information sequence.

35.   A receiver according to claim 25 wherein the first and second separated signals comprise first and second separated baseband signals.

36.   A receiver that receives a plurality of communications from a respective plurality of transmitters using a common carrier frequency, the receiver comprising:
a co-channel signal generator that generates a co-channel signal

5   responsive to the plurality of information signals;
a demodulator that demodulates the co-channel signal to provide an estimate of a first information sequence corresponding to a first one of the communications;
a decoder that decodes the estimate of the first information sequence

10   to improve the estimate of the first information sequence;
a re-encoder that re-encodes the improved estimate of the first information sequence;

a modulator that modulates the improved and re-encoded estimate of the first information sequence; and

15   a subtractor that subtracts the modulated estimate of the first information sequence from the co-channel signal to provide a second baseband signal wherein the demodulator demodulates the second signal to provide an estimate of a second information sequence corresponding to a second one of the communications.

37.   A receiver according to Claim 36 further comprising:
a processor that processes the estimates of the first and second information sequences to reproduce the first and second communications.

38.   A receiver according to Claim 36 wherein the decoder decodes the estimate of the second information sequence to improve the estimate of the second information sequence.

39.   A receiver according to Claim 38 wherein the re-encoder re-encodes the improved estimate of the second information sequence, wherein the modulator modulates the improved and re-encoded estimate of the second information sequence, wherein the subtractor subtracts the modulated

5   estimate of the second information sequence from the co-channel signal to provide a third signal, and wherein the demodulator demodulating the third signal to provide a second estimate of the first communication.

40.   A receiver according to Claim 39 wherein the decoder decodes the second estimate of the first information sequence.

41.   A receiver according to Claim 36 wherein the co-channel signal comprises a co-channel baseband signal and the second signal comprises a second baseband signal.

42.   A method for receiving a plurality of communications from a respective plurality of transmitters using a common carrier frequency, the method comprising the steps of:

receiving a plurality of information signals on a common carrier

5   frequency corresponding to the plurality of communications from the plurality

of transmitters;

generating first and second separated signals corresponding to

respective first and second ones of the information signals so that the first

separated signal includes a primary component corresponding to the first

10   information signal and so that the second separated signal includes a primary

component corresponding to the second information signal;

extrapolating the first separated signal to estimate an effect of the first

information signal on the second separated signal;

subtracting the estimate of the effect of the first information signal from

15   the second separated signal; and

estimating first and second information sequences respectively

corresponding to the first and second information signals.

43.   A method according to Claim 42 further comprising the step of:

processing the estimates of the first and second information sequences

to reproduce the first and second communications.

44.   A method according to Claim 42:

wherein the step of receiving the plurality of information signals

comprises receiving first and second co-channel signals from respective first

and second antennas; and

5   wherein the step of generating the first and second separated signals

comprises the steps of,

combining the first and second co-channel signals according to

a first combining branch to generate the first separated signal

corresponding to the first information signal, and

10   combining the first and second co-channel signals according to

a second combining branch to generate the second separated signal

corresponding to the second information signal.

45.   A method according to Claim 42:

wherein the step of receiving the plurality of information signals comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5   comprises the steps of,

filtering the co-channel signal using a first filter to generate the first separated signal corresponding to the first information signal, and

filtering the co-channel signal using a second filter different from the first filter to generate the second separated signal corresponding to

10   the second information signal.

46.   A method according to Claim 45 wherein the first filter comprises a first medium response estimate including timing information for the first information signal and the second filter comprises a second medium response estimate including timing information for the second information signal.

47.   A method according to Claim 42:

wherein the step of receiving the plurality of information signals comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5   comprises the steps of,

sampling the co-channel signal with a first sampling phase to generate a first sampled co-channel signal,

sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate a second sampled

10   co-channel signal,

combining the first and second sampled co-channel signals using a first filter combination to provide the first separated signal, and

combining the first and second sampled co-channel signals using a second filter combination to provide the second separated

15   signal.

48.   A method according to Claim 42:

wherein the step of receiving the plurality of information signals comprises receiving a co-channel signal; and

wherein the step of generating the first and second separated signals

5   comprises the steps of,

sampling the co-channel signal with a first sampling phase to generate the first separated signal, and

sampling the co-channel signal with a second sampling phase different than the first sampling phase to generate the second

10   separated signal.

49.   A method according to Claim 42 further comprising the steps of:

extrapolating the second separated signal to estimate an effect of the second information signal on the first separated signal; and

subtracting the estimate of the effect of the second information signal

5   from the first separated signal.

50.   A method according to Claim 42 wherein the first and second separated signals comprise first and second separated baseband signals.
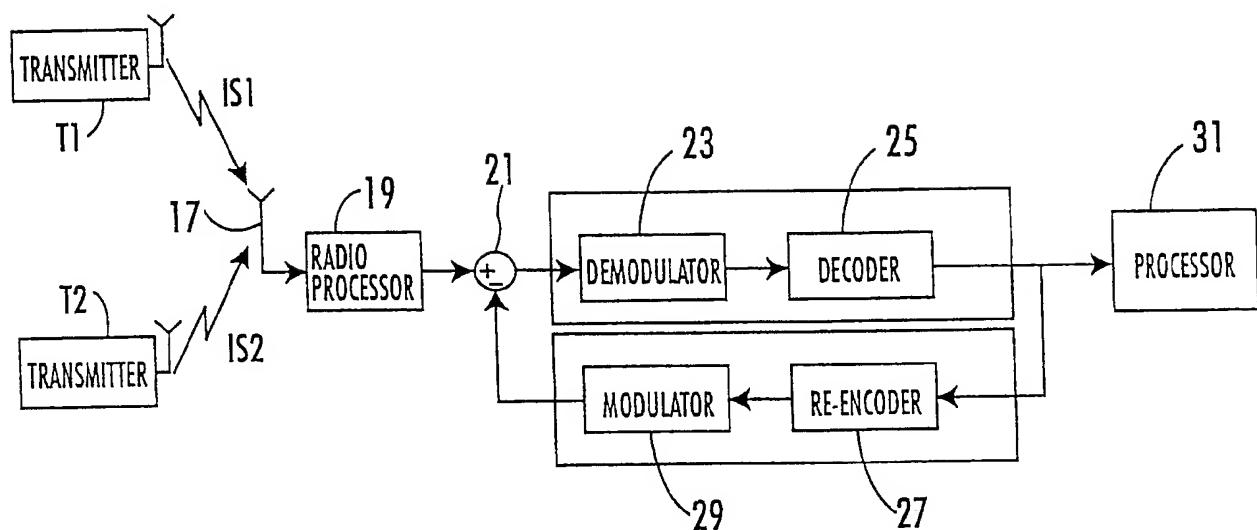
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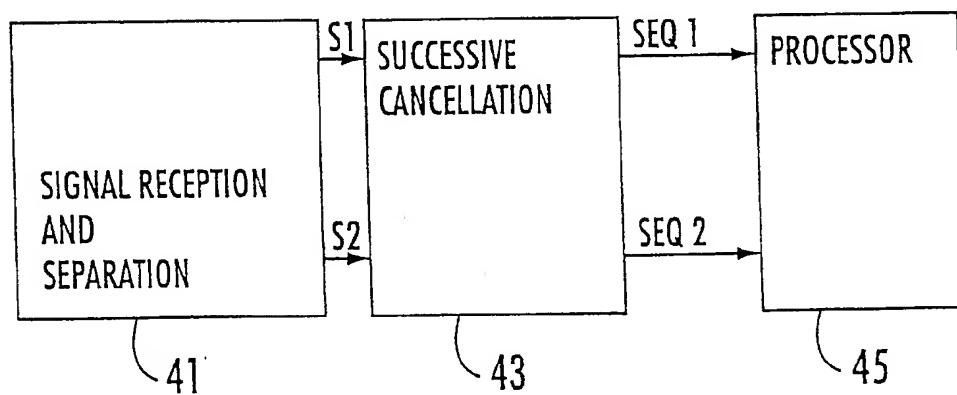
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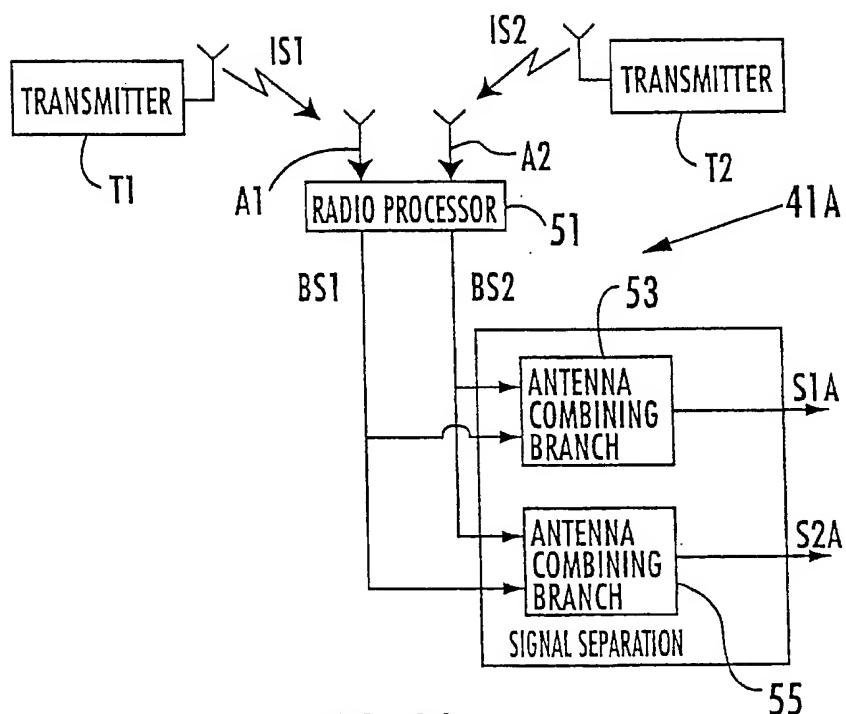
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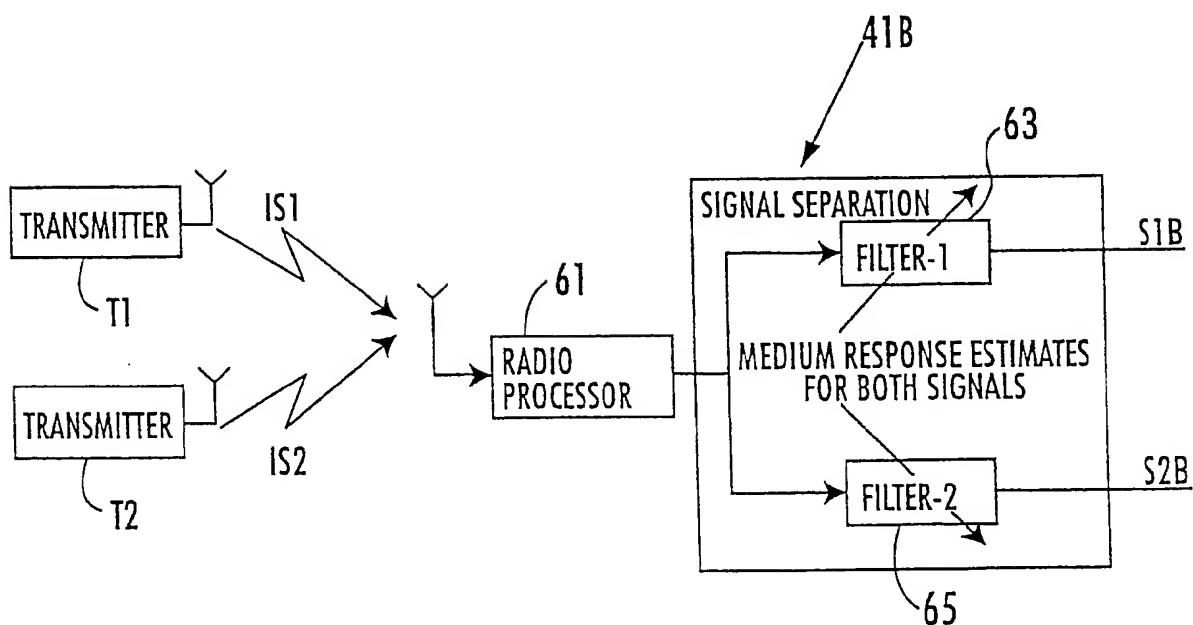
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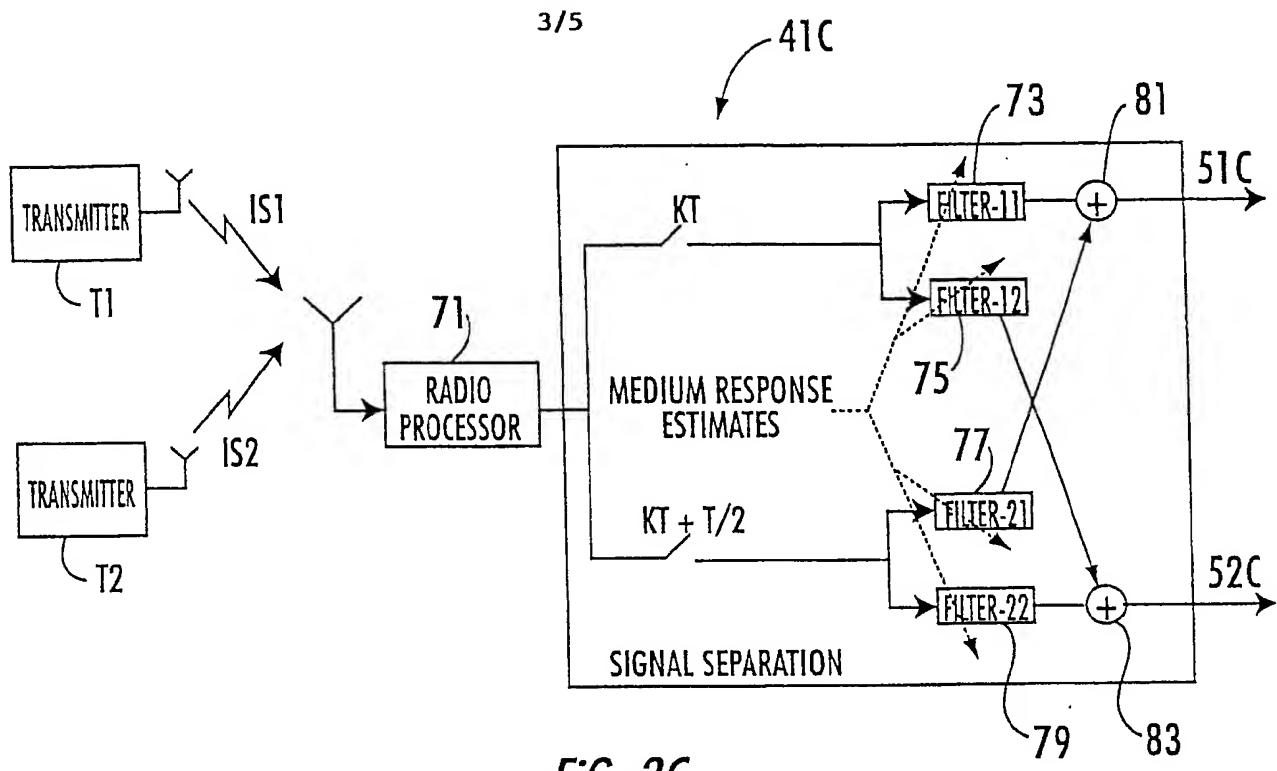
FIG. 3C
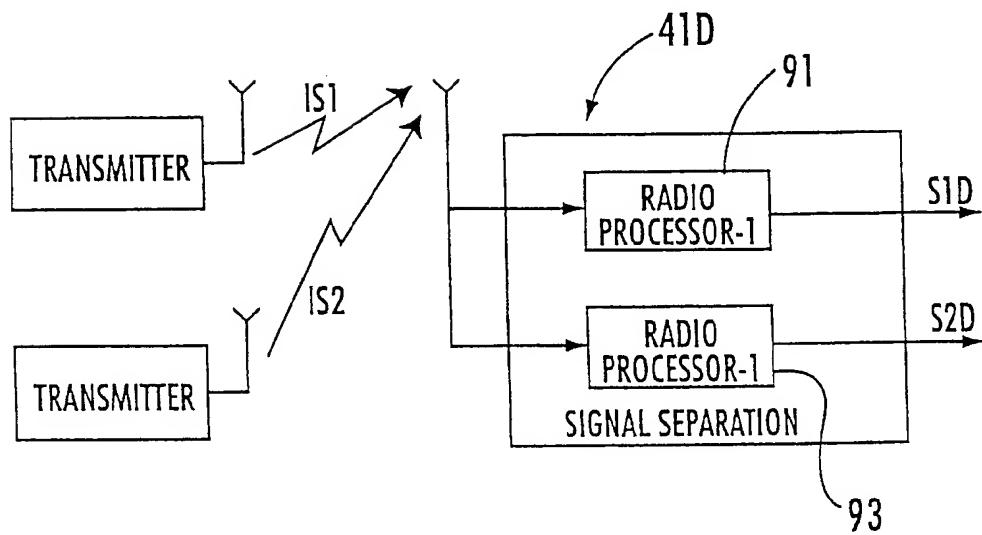

FIG. 3D
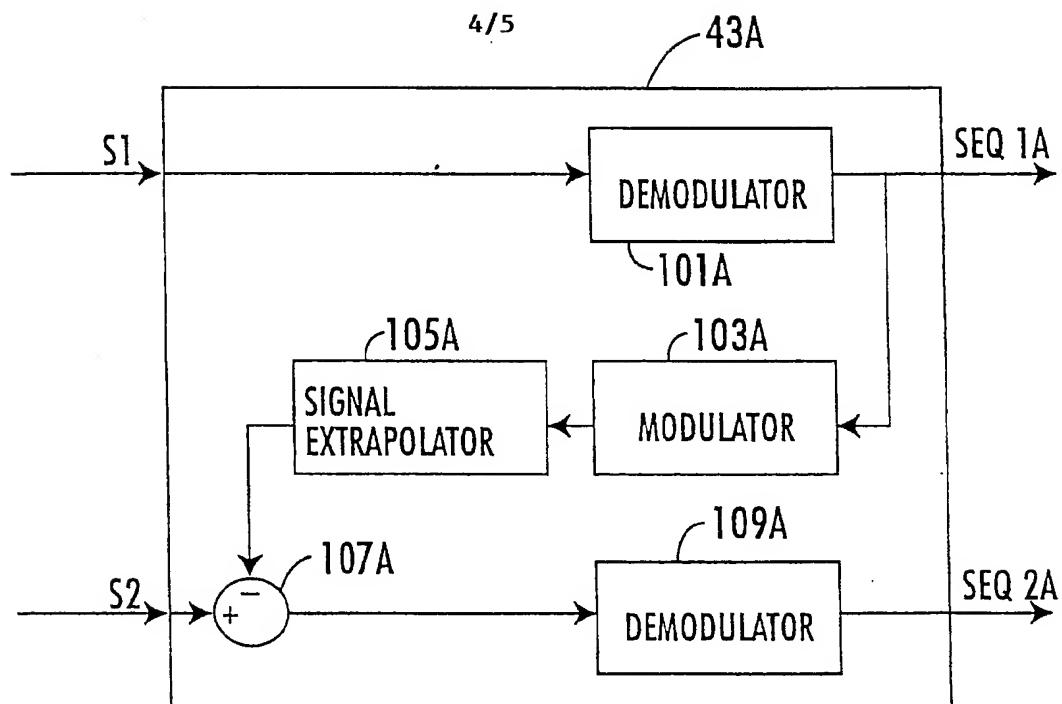
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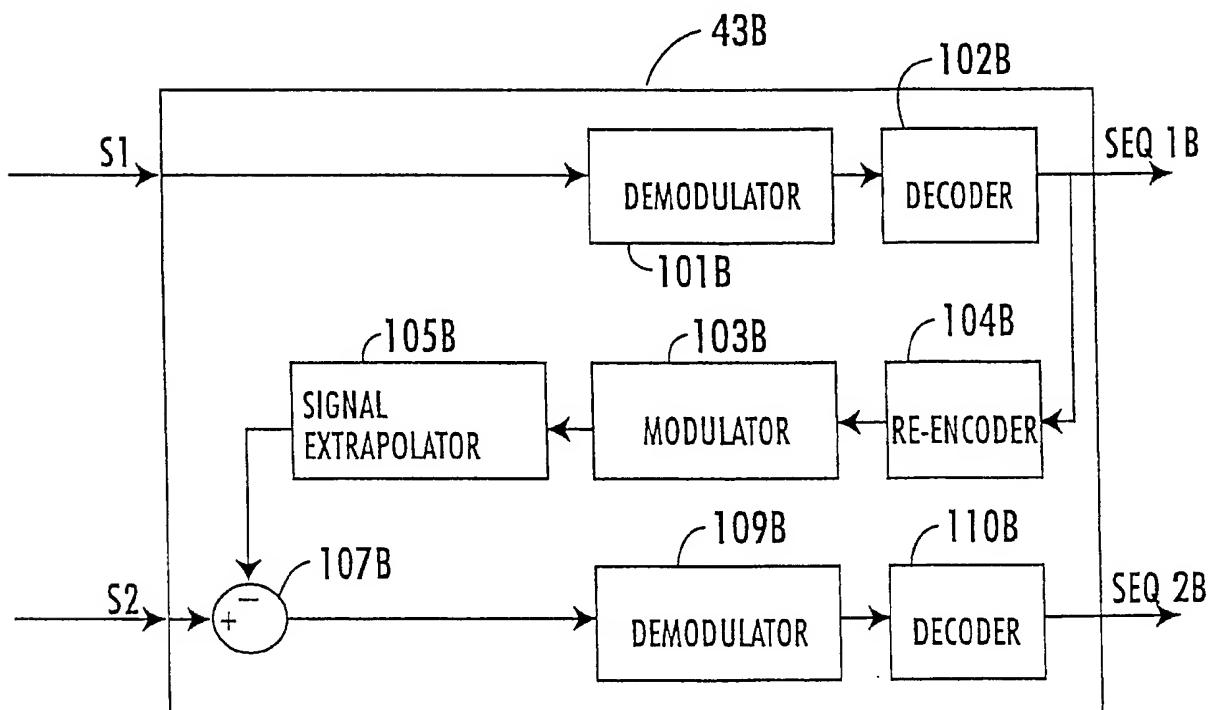
FiG. 4B

FiG. 4C
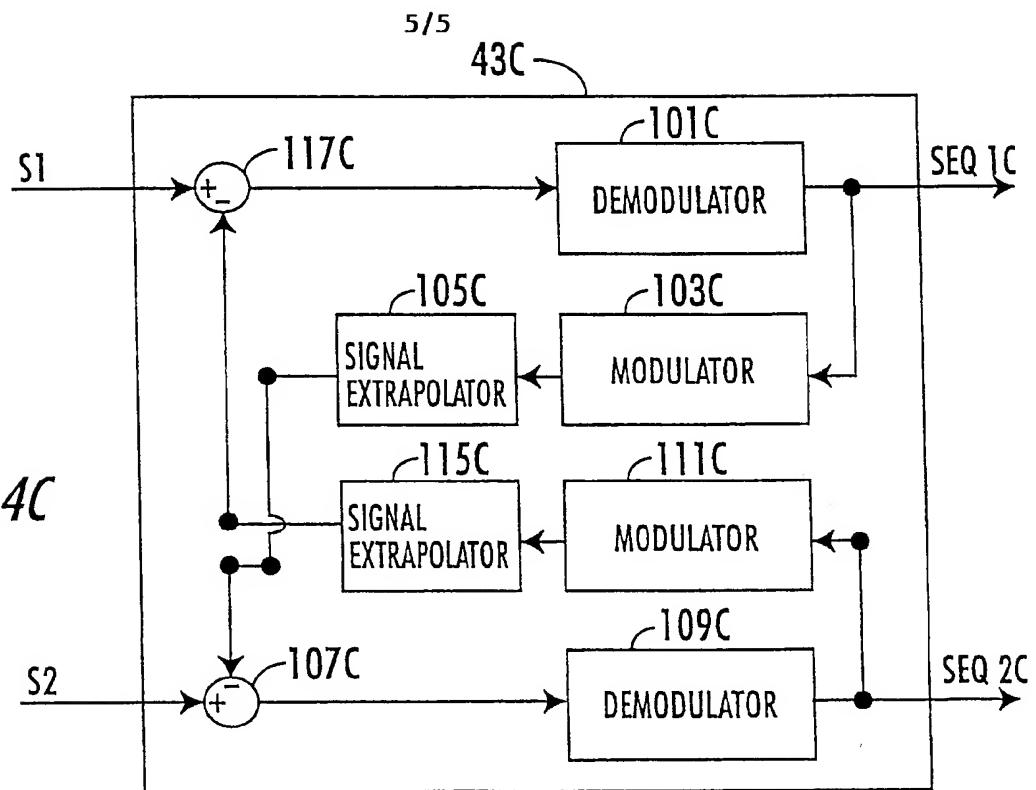
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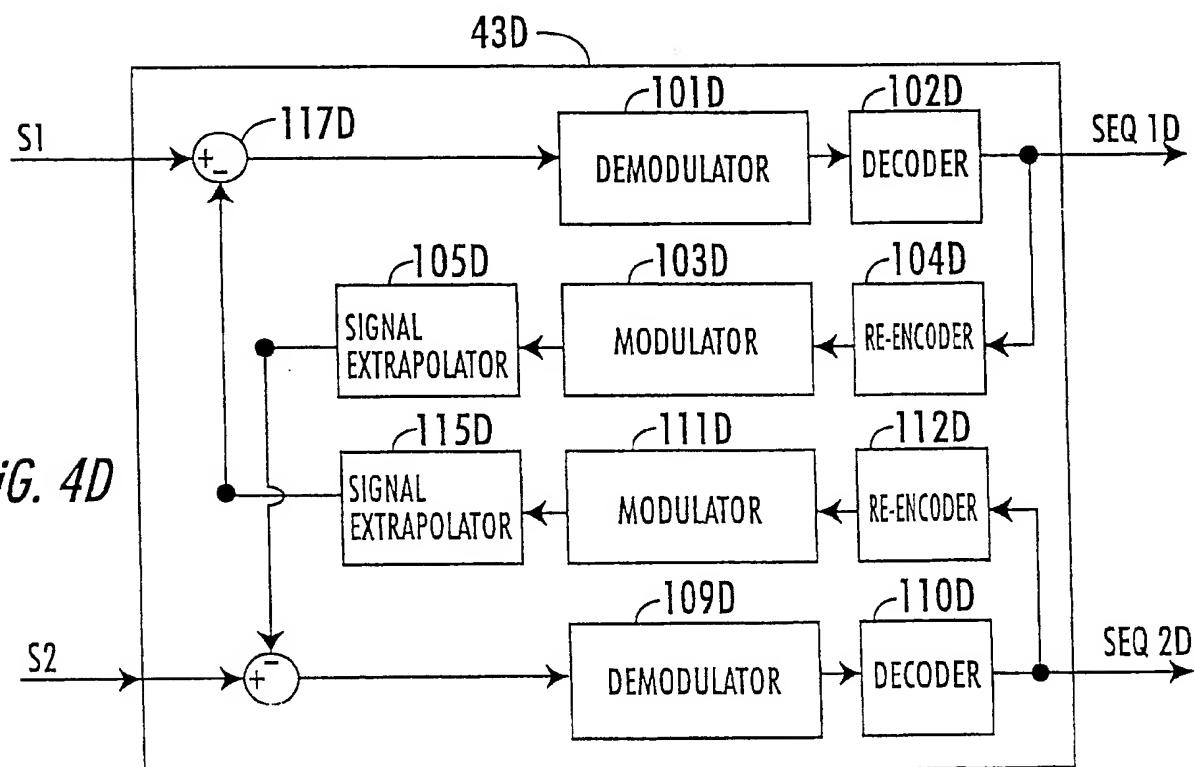
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 644 592 A (RAPHAELI DAN ET AL) 1 July 1997 (1997-07-01)	1-4, 6-27, 30-41
A	abstract column 3, line 50 -column 4, line 13; figures 1,2,4 column 5, line 51 -column 6, line 7 claims 1-3 --- -/--	42-50

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search	Date of mailing of the international search report
23 November 2000	04/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Ó Donnabháin, E

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 491 668 A (ERICSSON GE MOBILE COMMUNICAT) 24 June 1992 (1992-06-24)	13-15, 18, 20-24, 36-38,41
A	abstract figure 7 page 2, column 2, line 23 - line 32 page 3, column 3, line 10 - line 41 page 6, column 10, line 2 - line 35 claims 1,5 -----	1,25,42

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